Modeling for Sustainability

Edited by: Blair, Gordon ; Cheng, Betty ; Hilty, Lorenz ; Paige, Richard

Abstract: This report documents the program and the outcomes of Dagstuhl Seminar 18351 "Modeling for Sustainability", August 26–31, 2018. Many different kinds of models, from engineering models to scientific models, have to be integrated and coordinated to support sustainability systems such as smart grid or cities, i.e., dynamically adaptable resource management systems that aim to improve the technoeconomic, social, and environmental dimensions of sustainability. Scientific models help understand sustainability concerns and evaluate alternatives, while engineering models support the development of sustainability systems. As the complexity of these systems increases, many challenges are posed to the computing disciplines to make data and modelbased analysis results more accessible as well as integrate scientific and engineering models while balancing trade-offs among varied stakeholders. This seminar explored the intrinsic nature of both scientific and engineering models, the underlying differences in their respective foundations, and the challenges related to their integration, evolution, analysis, and simulation including the exploration of what-if scenarios. Sustainability systems must provide facilities for the curation and monitoring of data sets and models and enable flexible (open) data and model integration, e.g., physical laws, scientific models, regulations and preferences, possibly coming from different technological foundations, abstractions, scale, technological spaces, and world views. This also includes the continuous, automated acquisition and analysis of new data sets, as well as automated export of data sets, scenarios, and decisions. The main function is to support the generation of what-if scenarios to project the effects on the different sustainability dimensions, and support the evaluation of externalities, especially for non rapidly renewable resources. Since the predictions are necessarily probabilistic, the system must be able to assess the uncertainty inherent in all its actions and provide suitable representations of uncertainty understandable by users. In addition to generating what-if scenarios to explore alternate model instantiations, the tool should be capable of generating suggestions for how to reach user-specified goals including quantifiable impacts and driving the dynamic adaptation of sustainability systems. These powerful services must be made accessible to the population at large, regardless of their individual situation, social status, and level of education. This seminar explored how Model-Driven Engineering (MDE) will help to develop such an approach, and in particular i) how modeling frameworks would support the integration of the various heterogeneous models, including both engineering and scientific models; ii) how domain specific languages (DSLs) would (a) support the required socio-technical coordination, i.e., engage engineers, scientists, decision makers, communities, and the general public; and (b) integrate analysis/probabilistic/ user models into the control loop of smart CPS (cyber physical system). DSLs are also supposed to provide the right interface (in terms of abstractions/ constructs) to be used as tools for discovering problems and evaluating ideas. The seminar served to identify critical disciplines and stakeholders to address MDE for sustainability and the research roadmap of the MDE community with regards to the development of sustainability systems. In particular, the seminar identified and explored four key areas: 1) research challenges relevant to modeling for sustainability (M4S); 2) a multidisciplinary collection of relevant literature to provide the foundation for exploring the research challenges; 3) three case studies from different application domains that provide a vehicle for illustrating the M4S challenges and for validating relevant research techniques; and 4) the human and social aspects of M4S. The cumulative results of the work performed at the seminar and subsequent collaborations will help to establish the required foundations for integrating engineering and scientific models, and to explore the required management facilities for evaluating what-if scenarios and driving adaptive systems. In addition, we envision to produce as an outcome of the seminar a representative case study that will be used by the community to assess and validate contributions in the field of modeling for sustainability.

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Report from Dagstuhl Seminar 18351

Modeling for Sustainability

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 18351 "Modeling for Sustainability".

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1 Executive Summary

Gordon Blair
Betty H. C. Cheng
Lorenz Hilty
Richard F. Paige

Many different kinds of models, from engineering models to scientific models, have to be integrated and coordinated to support sustainability systems such as smart grid or cities, i.e., dynamically adaptable resource management systems that aim to improve the techno-economic, social, and environmental dimensions of sustainability. Scientific models help understand sustainability concerns and evaluate alternatives, while engineering models support the development of sustainability systems. As the complexity of these systems increases, many challenges are posed to the computing disciplines to make data and model-based analysis results more accessible as well as integrate scientific and engineering models while balancing trade-offs among varied stakeholders. This seminar explored the intrinsic nature of both scientific and engineering models, the underlying differences in their respective foundations, and the challenges related to their integration, evolution, analysis, and simulation including the exploration of what-if scenarios.

Sustainability systems must provide facilities for the curation and monitoring of data sets and models and enable flexible (open) data and model integration, e.g., physical laws, scientific models, regulations and preferences, possibly coming from different technological foundations, abstractions, scale, technological spaces, and world views. This also includes the continuous, automated acquisition and analysis of new data sets, as well as automated export of data sets, scenarios, and decisions. The main function is to support the generation of what-if scenarios to project the effects on the different sustainability dimensions, and support the evaluation of externalities, especially for non rapidly renewable resources. Since the predictions are necessarily probabilistic, the system must be able to assess the uncertainty inherent in all its actions and provide suitable representations of uncertainty understandable by users. In addition to generating what-if scenarios to explore alternate model instantiations, the tool should be capable of generating suggestions for how to reach user-specified goals including quantifiable impacts and driving the dynamic adaptation of sustainability systems. These powerful services must be made accessible to the population at large, regardless of their individual situation, social status, and level of education.

This seminar explored how Model-Driven Engineering (MDE) will help to develop such an approach, and in particular i) how modeling frameworks would support the integration of the various heterogeneous models, including both engineering and scientific models; ii) how domain specific languages (DSLs) would (a) support the required socio-technical coordination, i.e., engage engineers, scientists, decision makers, communities, and the general public; and (b) integrate analysis/probabilistic/user models into the control loop of smart CPS (cyber physical system). DSLs are also supposed to provide the right interface (in terms of abstractions/constructs) to be used as tools for discovering problems and evaluating ideas.

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The cumulative results of the work performed at the seminar and subsequent collaborations will help to establish the required foundations for integrating engineering and scientific models, and to explore the required management facilities for evaluating what-if scenarios and driving adaptive systems. In addition, we envision to produce as an outcome of the seminar a representative case study that will be used by the community to assess and validate contributions in the field of modeling for sustainability.

2 Table of Contents

3 Overview of Talks

3.1 Models of and for Sustainability in my domain

Lucy Bastin (Aston University – Birmingham, GB)

My background is multi-disciplinary – from zoologist to GIS software developer to researcher at the policy interface, which has covered pretty much all the types of models that have been mentioned so far. I will focus on some additional sustainability definitions from my current work which may be relevant to our discussions. The first is classic environmental "sustainability" whose ultimate goal is SDGs, aimed at sustaining human life on earth at a certain quality. We aim to conserve biodiversity and ecosystem services by sharing benefits / reducing human/wildlife conflict. This involves

- observing, sampling and modelling that biodiversity,
- inference / transformation to estimate the ecosystem services it supports,
- prediction of the likely human actions, landscape modifications and movements that will affect biodiversity,
- prediction of the ways that people and wildlife will respond to climate and infrastructure changes,
- multi-objective planning with diverse stakeholders,
- identification of the pinch points in the landscape where support will be needed.

The second type of sustainability relates to persistence and robustness of data infrastructures, legal and regulatory systems and knowledge communities – often in the context of very unstable political / economic situations. Barriers to data sharing are usually more cultural than technical. The data accessible to us is in itself a syntactic model of what mattered to the original funders (for example, REDD+ and carbon capture); this leads to data being reused for inappropriate purposes and increased uncertainty. 2 practical challenges from my domain: (1) Metadata and quality information in citizen science. (2) Reasoning about intersection between polygons representing protected areas and species ranges when these are bounded by lines of different types and of varying mobility (coastlines, political boundaries, physical fences) but the topological model necessary to capture this nuance is no longer in common use by commercial or open source GIS software.

3.2 Beyond Scientific Rationality: Why we need Critical Systems Thinking

Christoph Becker (University of Toronto, CA)

This talk outlined the normative character and inevitable value basis of modelling activities in computing and showed why and how critical perspectives are needed to address the key question of practical reason in modelling for sustainability: "How can we rationally justify the normative consequences of our models?".

Models in science and engineering are traditionally based on the tradition of the scientific method and inherit its realist ontology and objectivist epistemological foundations. Software

Engineering and Computing are based on this tradition, but are both about what *is* and what *ought to be*, i.e., design. The resulting models are enacted into behavior that acts with the world and changes it. Modelling involves assumptions that are in turn contingent upon unspoken beliefs – there are always decisions outside the model's justification. Underneath the surface lie moral and political decisions based on values. The talk offered a little Devil's Dictionary [1] of modelling to illustrate that computing tends to overlook these.

Unfortunately, scientific rationality misapplied to social systems [2] often fails to take into account the 'purposeful nature' of humans and social systems [3]. In assuming an objective goal function is given and unproblematic, it fails to account for the fact that it is often that goal function that is problematic [5], and that multiple contradictory views on the issues arising in a situation cannot be resolved away using scientific logic [4]. As a consequence, scientific rationality often suggests that the decisions it cannot reason about are simply irrational – and that is a mistake: This perspective "reduces practical reason to theoretical reason" [6] and ultimately fails to be relevant to the question at hand [7].

Since all models relevant to sustainability have normative consequences, they also have to be *legitimate*. The scientific method cannot legitimate them, because it has no access to values, moral and politics [8]. Neither can engineering theory on its own: Instrumental rationality cannot legitimate the normative implications of its own consequences [6], because it similarly cannot reason rationally about values, moral and politics. This makes it no less important to address the key question. Critical Theory and Critical Systems Thinking are essential perspectives that must be considered to begin addressing that challenge. To do so, computing must collaborate deeply with social disciplines. This raises well-known challenges [9], but cannot and must not be avoided.

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3.3 Modelling with the Life Cycle Assessment (LCA) Framework

Didier Beloin-Saint-Pierre (Empa-Akademie – Zürich, CH)

The life cycle assessment (LCA) framework defines different modelling choices and assumptions to provide an evaluation of the environmental sustainability of products, services or systems.

The basis of this assessment is made from the quantitative comparison of environmental impacts from different options (i.e. products, services or systems) which have equivalent functions (e.g. provide electricity). These evaluated impacts cover a wide range of indicators (e.g. global warming potential, ecotoxicity, primary energy use) that occur all over the world and within the full life cycle of the considered options (i.e. natural resource extraction, manufacturing, use of product/service and end-of-life management). This comprehensive picture is essential to offer an assessment of sustainability and also helps in detecting potential impact displacement between indicators, regions and periods of time. When the modelling is finished, the option with lower environmental impacts is then considered more environmentally sustainable than the others [1]. This type of conclusion (i.e. more or less sustainable) highlights that LCA typically performs best when it offers a relative assessment of sustainability.

The environmental sustainability assessment that is carried out with the LCA framework uses two types of model. The first type describes the human activities with processes, product flows (i.e. link between processes) and their interactions with the environment (i.e. extracted natural resources and emissions of pollutants which are called elementary flows in LCA). The second type of model (i.e. life cycle impact assessment models) aggregates and translates the elementary flows into different environmental impacts. Such impacts can then be more or less aggregated into different indicators to offer information that fits the needs of decision-makers. Results can be presented with their uncertainties to provide more insights on the degree of confidence that LCA practitioners have on their work.

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3.4 The Role of Runtime Models for Decision Making in Sustainable Systems

Nelly Bencomo (Aston University – Birmingham, GB)

In this short presentation I talked about how to use models (design, runtime models and other models) to inform decision making wrt sustainability. I focus specially on the case of runtime models. I argue that models that support decision-making need to be updated over time. For example, new decisions will need to be reflected on the system while the loop continues. Decisions are related to the trade-offs between different quality properties related to sustainability. Runtime models can support the process of "IF-analysis" required to study the consequences of new decisions inserted.

3.5 Sustainability Debt: A Metaphor to Support Sustainability-Aware Software Systems Engineering

Stefanie Betz (KIT – Karlsruher Institut für Technologie, DE)

Joint work of Stefanie Betz, Christoph Becker, Ruzanna Chitchyan, Leticia Duboc, Steve M. Easterbrook, Birgit Penzenstadler, Norbert Seyff, Colin C. Venters
Main reference Stefanie Betz, Christoph Becker, Ruzanna Chitchyan, Leticia Duboc, Steve M. Easterbrook, Birgit Penzenstadler, Norbert Seyff, Colin C. Venters: "Sustainability Debt: A Metaphor to Support Sustainability Design Decisions", in Proc. of the Fourth International Workshop on Requirements Engineering for Sustainable Systems, RE4SuSy 2015, co-located with the 23rd IEEE International Requirements Engineering Conference (RE 2015), Ottawa, Canada, August 24, 2015., CEUR Workshop Proceedings, Vol. 1416, pp. 55–53, CEUR-WS.org, 2015.
URL http://ceur-ws.org/Vol-1416/Session2Paper4.pdf

This talk introduces the concept of sustainability debt. The metaphor helps in the discovery, documentation, and communication of sustainability issues in requirements engineering. Sustainability debt builds on the existing metaphor of technical debt and extend it to four other dimensions of sustainability to help think about sustainability-aware software systems engineering. It highlights the meaning of debt in each dimension and the relationships between those dimensions. Finally, it discusses the imitations and challenges of the metaphor sustainability debt.

3.6 Modelling for Natural Flood Management

Keith Beven (Lancaster University, GB)

Main reference Peter Metcalfe, Keith Beven, Barry Hankin, Rob Lamb: "A modelling framework for evaluation of the hydrological impacts of nature-based approaches to flood risk management, with application to in-channel interventions across a 29-km2 scale catchment in the United Kingdom", in Hydrological Processes, Vol. 31(9), pp. 1734–1748, 2017.
URL https://doi.org/10.1002/hyp.11140

Natural Flood Management (NFM) is proposed as a way of mitigating the damages of significant floods by distributed land management and storage of water in upstream catchment areas so as to reduce peak flows in areas at risk of flooding. This implies some decisions about investment in NFM measures, with assessment of resulting benefits (and potential dis-benefits). This will normally be achieved by modelling the impact of implementing NFM measures using hydrological runoff generation models that cascade inputs to hydraulic flood routing and flood inundation models. Impacts will often be assessed with reference to past historical floods, but because it is expected that flood frequencies might be changing as a result of climate change, might also involve some assessment of what future climate impacts on rainfalls and evapotranspiration might mean (using some form of weather generator model based on an ensemble of climate models) [1]. This represents a specific example of Modelling for sustainability for an environmental problem which involves significant sources of epistemic uncertainty, including the representation of runoff and flood routing processes; errors in input and evaluation data; effective values of model parameters; and potential scenarios of future boundary conditions.

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1 Peter Metcalfe, Keith Beven, Barry Hankin, and Rob Lamb. A modelling framework for evaluation of the hydrological impacts of nature based approaches to flood risk management, with application to inchannel interventions across a 29km2 scale catchment in the United Kingdom. *Hydrological Processes*, 31(9):1734–1748, 2017

3.7 Working Together for Digitally Inspired Environmental Science

Gordon Blair (Lancaster University, GB)

Joint work of Ensemble Projects, Lancaster University
Main reference William Simm, Faiza Samreen, R. Bassett, Maria Angela Ferrario, Gordon S. Blair, Jonathan Whittle, P. J. Young: "SE in ES: opportunities for software engineering and cloud computing in environmental science", in Proc. of the 40th International Conference on Software Engineering: Software Engineering in Society, ICSE (SEIS) 2018, Gothenburg, Sweden, May 27 – June 03, 2018, pp. 61–70, ACM, 2018.
URL http://dx.doi.org/10.1145/3183428.3183430

Environmental science is at a crossroads as it is faced with new scientific challenges around climate change. There is a pressing need for a new kind of science in respond to this challenge, that is a science that is more open, integrated and collaborative. To support this, there is an equal need for new tools and techniques to support this style of science.

Ensemble is an umbrella initiative examining the role of technology in supporting this new kind of environmental science. It is a fundamentally trans-disciplinary initiative involving data scientists, computer scientists, experts in communication and also earth and environmental sciences. The broader programme is looking at a range of technologies, specifically new means of data acquisition at different scales (from the use of Internet of Things technology through to remote sensing), new techniques for making sense of the resultant rich but highly heterogeneous data sets (through emerging data science techniques tailored for the needs of environmental science), and also new technological infrastructure offering the elastic capacity for the storage and processing of this data (through the use of cloud computing).

A key aspect of this research is supporting environmental modelling in the cloud, with this work being carried out as part of the EPSRC-funded project "Models in the Cloud: Generative Software Frameworks to Support the Execution of Environmental Models in the Cloud" (EP/N027736/1). This work aims to make it easier for environmental modellers to run modelling experiments in the cloud through exploiting contemporary software engineering techniques, most notably model-driven engineering, to raise the level of abstraction of such platforms. This talk will explore results from this research project, including the application of such techniques in two contrasting areas of environmental science (related to climate science and hydrology respectively).

3.8 Modeling for Sustainability: the Software Engineering Perspective

Ruzanna Chitchyan (University of Bristol, GB)

In this talk I present the perspective that Software Engineering discipline has traditionally taken on the modelling and software generation activities. This traditional viewpoint is contrasted to the challenges posed by the Sustainability concern. In particular, I argue that:

(i) the constantly evolving notion of sustainability requires constant re-evaluation and adaptation of the models;

(ii) sustainability implies impact consideration at planetary scale, thus models of planetary scale are essential if the impact of the developed system is to be understood;

(iii) sustainability requires close consideration of social concerns, thus necessitating close, explicit, and continuous integration between social and technical models.

3.9 Modeling for Sustainability: Or How to Make Smart CPS Smarter?

Benoit Combemale (University of Toulouse, FR)

Main reference Benoît Combemale, Betty H. C. Cheng, Ana Moreira, Jean-Michel Bruel, Jeffrey G. Gray: "Modeling for sustainability", in Proc. of the 8th International Workshop on Modeling in Software Engineering, MiSE@ICSE 2016, Austin, Texas, USA, May 16-17, 2016, pp. 62–66, ACM, 2016.
URL http://dx.doi.org/10.1145/2896982.2896992

Various disciplines use models for different purposes. An engineering model, including a software engineering model, is often developed to guide the construction of a non-existent system. A scientific model is created to better understand an existing phenomenon (i.e., an already existing system or a physical phenomenon). An engineering model may incorporate scientific models to build a smart cyber-physical system (CPS) that require an understanding of the surrounding environment to decide of the relevant adaptation to apply. Sustainability systems, i.e., smart CPS managing resource production, transport and consumption for the sake of sustainability (e.g., smart grid, city, farming system), are typical examples of smart CPS. Due to the inherent complex nature of sustainability that must delicately balance trade-offs between social, environmental, and economic concerns, modeling challenges abound for both the scientific and engineering disciplines.

In this talk, I present a vision that promotes a unique approach combining engineering and scientific models to enable informed decision on the basis of open and scientific knowledge, a broader engagement of society for addressing sustainability concerns, and incorporate those decisions in the control loop of smart CPS. I introduce a research roadmap to support this vision that emphasizes the socio-technical benefits of modeling.

3.10 Modeling for Sustainability: How Quality Requirements Contribute to Sustainability?

Nelly Condori-Fernandez (Free University Amsterdam, NL)

Main reference Nelly Condori-Fernández, Patricia Lago: "Characterizing the contribution of quality requirements to software sustainability", Journal of Systems and Software, Vol. 137, pp. 289–305, 2018.
URL http://dx.doi.org/10.1016/j.jss.2017.12.005

The assessment and design based on the notion of sustainability requirements are still poorly understood. There is no consensus on which sustainability requirements should be considered. This talk introduces briefly the meaning about modeling for sustainability and highlights the importance of involving stakeholders for identifying requirements that can contribute the economic, technical, environmental and social sustainability dimensions of software-intensive systems. Also we argue that the relevance of the different dimensions depends on the type of software system.

With the purpose of defining a context-dependent sustainability model for software intensive systems, we present the design and main results of a survey that involves different target audiences (e.g. software architects, ICT practitioners with expertise in Sustainability, requirements engineers, and project managers).

3.11 Modelling Sustainability in Technology Transfer

Letícia Duboc (Ramon Llul University, ES)

Much of the software-based technology that surrounds our lives have their roots in universities research labs. However, transferring technology from the labs to the society is a complex process and putting in place a strategy to do so effectively is very challenging. This talk discusses some of the challenges on modelling sustainability in the context of technology transfer.

3.12 Modelling for Sustainability

Joao Goncalves (Empa-Akademie – Zürich, CH)

"Two examples and considerations about modelling"

The first presented modelling domain relates to microscopic traffic simulation. As a general consideration, modelling and simulation can be used not only as a means to visualise, interpret and quantify a system, but also as a replacement of field testing. In particular regard to sustainability, this substitution results in a compression of test times and can effectively reduce the necessary resources to conduct experiments.

The second presented application describes an ongoing work that attempts to discover and evaluate pathways to a post-fossil Switzerland. Translating the system outputs to stakeholders and further applying their actions to the system constitutes an additional challenge.

Modelling for sustainability can be defined as the usage of modelling methodologies to consciously "optimise" sustainable usage of resources. However, if such studies are to have a significant impact on sustainability, Informatics must be used as a tool to translate complex and domain-specific assessments to non-experts and decision makers.

3.13 Modeling for Sustainability

Øystein Haugen (Ostfold University College – Halden, NO)

What is a Model? What is Modeling? What is Modeling for Sustainability? Models should execute/behave and mimic a referent system. Modeling is the creation and evolution of a model. Modeling for sustainability is when the referent system is concerned with sustainability.

3.14 Modeling to Reduce Waste in Chemical Production

Øystein Haugen (Ostfold University College – Halden, NO) and Per-Olav Hansen

This talk presented a use-case in the European ECSEL project Productive4.0 owned by Unger Fabrikker in Norway and executed by the Norwegian consortium in Productive4.0. The use-case is about reducing the waste originating from the transition period between the production of two high-quality chemical products. During the transition period, no proper product is produced and this produce must be further handled as waste. The purpose of the use-case is to find models that can make it possible to reduce the transition period and the amount of potential waste.

3.15 Reflections on Marvin Minsky's Definition of "Model"

Lorenz Hilty (Universität Zürich, CH)

"To an observer B, an object A* is a model of an object A to the extent that B can use A* to answer questions that interest him about A." [1], p. 426.

This definition includes concrete, tangible models as well as conceptual models that are described in (usually formal) languages. The definition has some fruitful implications:

- The purpose of a model can be described by specifying the type of questions the model is intended to answer about the original (A).
- The purpose of a model is connected to the (epistemic) interest of an observer.

- There can be multiple models of the same original, depending on the purpose. Zeigler calls two models complementary if they embody consistent hypotheses about the original (but in a different way), and competitive if they embody mutually exclusive hypotheses [2], p. 13.
- The term "representation" can be avoided in the definition of "model". I consider this an advantage because "representation" is a term that raises many epistemological issues.
- The terms "abstraction" and "simplification" can be avoided in the definition of "model". Characterizing models as abstractions or simplifications implies there could be an entity that is "no abstraction" or "no simplification" of another entity (something like a "perfect copy", which is however not a model because it is no abstraction or simplification), an idea that again raises epistemological issues.
- Both descriptive and prescriptive models can be subsumed under Minsky's definition, namely in the following way: If A already exists, the model is descriptive, otherwise (if A is to be created), the model is prescriptive. In the latter case, the "questions that interest [the observer] about A" are addressing the consequences of design decisions regarding A. If A exists and we are interested in future changes A may undergo (or of impacts A will be subjected to), the model is descriptive and prescriptive.
- We can ask how a model is used to generate answers to questions. "Generating aswers" is often done by some sort of experimentation, e.g., by setting parameters and initial conditions to create an instance of the model and let an algorithm interpret it. Simulation can thus be defined as experimenting with a model. (If there is no need for experimentation, we are in the exceptional situation that the model is simple enough to be treated analytically.)
- Because a model is not a statement, but a generator for a (usually infinite) set of statements about the original, it is usually not verifiable, but falsifiable.

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3.16 Sustainability: Scientific Theories and Models

Jean-Marc Jézéquel (IRISA – Rennes, FR)

Joint work of Diverse Team, at IRISA/Inria Rennes

A Model is an abstraction of an aspect of the world for a specific purpose. Therefore a Scientific Theory for supporting sustainability is a Model (but a Model is not always a Scientific Theory, eg. because it might not be falsifiable). In facts, Creating a Scientific Theory is (evermore) Writing Software. Conversely writing (useful) Software is like Creating a Scientific Theory, with validation tests playing the role of experiments in science. In this talk we explore how MDE technology could be used to support scientific theories of sustainability.

3.17 Modeling of Sustainability: Sustainable Software Engineering

Eva Kern (Universität Lüneburg, DE)

Main reference Stefan Naumann, Markus Dick, Eva Kern, Timo Johann: "The GREENSOFT Model: A Reference Model for Green and Sustainable Software and its Engineering," In: Sustainable Computing: Informatics and Systems, 1(4):294–304, 2011.
URL https://doi.org/10.1016/j.suscom.2011.06.004

This talk summarized the way of modeling for sustainability of software. Giving a general short introduction into models of the field of software engineering, it presents different kinds of models of the field of green and sustainable software engineering: a life cycle model for sustainable software products, a reference model for green software and its engineering, procedure models for green software engineering, a measurement model to analyze the consumption of energy and resources while using software, and a quality model for sustainable software.

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3.18 Modelling for Sustainability in the Now

Jörg Kienzle (McGill University – Montreal, CA)

This short presentation takes a critical look at our ever increasing capability to model and make predictions about the future. The talk points out the very real possibility of abuse of this capability if it is not made available to the population at large. The talk ends by pointing out the inevitability of change, and consequently the continuous need to adapt.

3.19 Modeling for Sustainability: Challanges and Modeling Examples in Green Software

Sedef Akinli Kocak (Ryerson University – Toronto, CA)

Joint work of Sedef Akinli Kocak, Gulfem Alptekin, Ayse Basar Bener, Patricia Lago, Ivica Crnkovic, Birgit Penzenstadler

Different models have been developed and used in science and engineering disciplines. This talk gives a short introduction into what modeling is in general and summarizes main purpose of modeling for sustainability and challenging issues. The main challenging issues include taking interdisciplinary approach, managing uncertainty, taking long-term and global-local perspectives, and stakeholders participation with integration of their values and objectives. Then different modeling efforts have been presented in the area of green software and software for sustainability. The first presented one is based on modeling energy consumption of software products based on quantitative analysis [1]. The second presented modeling effort is multi-criteria decision making for software quality model. The third presented modeling is framing sustainability as a product quality [2]. The talk finalizes with take away question: how can models be developed and/or improved for sustainability purposes and used in support of decision-making?

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3.20 Models of Programming Languages

Peter D. Mosses (TU Delft, NL)

Joint work of L. Thomas van Binsbergen, Neil Sculthorpe, Peter D. Mosses, et al.
Main reference L. Thomas van Binsbergen, Neil Sculthorpe, Peter D. Mosses: "Tool support for component-based semantics", in Proc. of the Companion 15th International Conference on Modularity, Málaga, Spain, March 14–18, 2016, pp. 8–11, ACM, 2016.
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My research domain is meta-languages and tool support for specifying models of programming languages. This brief presentation first recalled the main features of such models, and the kinds of meta-languages typically used to specify them.

The PLanCompS project has developed a component-based approach to modelling programming languages. The semantics of each language construct is specified by translating it to an open-ended library of so-called 'funcons' (fundamental programming constructs). The behaviour of each funcon is fixed, and its definition does not change when new funcons are added. The beta-release of an initial library of funcons is available, together with some illustrative component-based specifications (at https://plancomps.github.io/CBS-beta).

The component-based approach supports reuse and co-evolution when modelling programming languages. This could encourage use of formal models by language developers, which might lead to better language design, and perhaps ultimately reduce waste of resources due to software bugs and lack of portability, but there appears to be no direct relevance to modelling for sustainability. It might however be interesting to investigate whether the component-based approach could be exploited for general modelling.

3.21 MDE and Sustainability: Questions

Gunter Mussbacher (McGill University – Montreal, CA)

Model-Driven Engineering (MDE) is based on the premise that each model conforms to a well-defined language (metamodel / grammar / profile) which specifies the concepts and relationships of a domain (i.e., abstract syntax), their representation (i.e., concrete grammar), as well as their meaning (i.e., semantics). A model is an abstraction of reality. It is a simplified, purposeful representation of a specific property/quality adjusted to human needs, hence reducing complexity to the human scale. To be useful, a model must be accurate and concise. Given these characteristics, a model enables humans to understand a domain, to communicate, to reason about it and make predictions about the property/quality, and – in some cases – implement the system. Is sustainability just another quality that can be handled like all other qualities? What is different? Is it the heterogeneity of the set of required models? Is it the uncertainty that needs to be reflected in the models? Is it continuous systems vs. discrete systems? Is it system thinking vs. divide and conquer?

3.22 Modeling for Sustainability in Software Engineering

Oscar M. Nierstrasz (Universität Bern, CH)

Software Engineering (SE) models abstract from objects of a given domain, whether real or virtual, in order to support reasoning or communication. Models may be descriptive, describing existing artifacts, or prescriptive, specifying something yet to be built. Models may support sustainability of SE processes, i.e., to ensure sustainable cost over time, or sustainability of SE artifacts, i.e., to ensure that code will be maintainable in the long term.

3.23 Modeling and Sustainability: Fitness-for-Purpose and Process

Richard F. Paige (University of York, GB)

Models are created for a purpose, and must ultimately be judged as fit for that purpose. What measures, metrics and qualities are important for understanding fitness-for-purpose for sustainability models? In traditional software engineering we are concerned with qualities such as correctness and consistency, whereas for sustainability (where models may live on for many years and may be managed by different people with different skills) other qualities, such as habitability, may be more important.

Similarly, models are created following different processes, including bottom-up (based on examples), top-down (using a domain-specific modeling language or general-purpose modeling language), via democratic process, via automatic generation, etc. Some models are left partially tacit or implicit via certain modeling processes. What is a suitable process for engineering the complex heterogeneous modeling collections that are needed for sustainability engineering?

3.24 5 Dimensions of Sustainability, Sustainability Analysis Diagram, and Leverage Points

Birgit Penzenstadler (California State University, US)

Joint work of Christoph Becker, Stefanie Betz, Ruzanna Chitchyan, Leticia Duboc, Steve M. Easterbrook, Birgit Penzenstadler, Norbert Seyff, Colin C. Venters
Main reference Christoph Becker, Stefanie Betz, Ruzanna Chitchyan, Leticia Duboc, Steve M. Easterbrook, Birgit Penzenstadler, Norbert Seyff, Colin C. Venters: "Requirements: The Key to Sustainability", IEEE Software, Vol. 33(1), pp. 56–65, 2016.
URL http://dx.doi.org/10.1109/MS.2015.158

In the area of requirements engineering we, inter alia, use models to illustrate concepts and come to agreements about the context and the system under development amongst a wide range of stakeholders. For that, we use five dimensions of sustainability (individual, social, economic, technical, and environmental) as well as three orders of effects (immediate, enabling, and structural) and depict a summary of this in a sustainability analysis diagram. Furthermore, we have applied the concept of leverage points (cf. Donella Meadows) to software systems for sustainability to understand how developers can use systems thinking to consider their designs in a larger context.

- What is your definition of modeling? Modeling is the abstraction from and representation of real world to conceptual elements and relations between them. In requirements engineering, we do this in often informal or semi-formal and illustrative ways.
- What is meant by "modeling for sustainability" in your domain/area of work? We try to develop (software) systems that support the use of our planet preserving its capacity to support living on it.

3.25 Contributions in Software Engineering and Green IT

Lionel Seinturier (Lille I University, FR)

Main reference Maxime Colmant, Romain Rouvoy, Mascha Kurpicz, Anita Sobe, Pascal Felber, Lionel Seinturier: "The next 700 CPU power models", Journal of Systems and Software, Vol. 144, pp. 382–396, 2018.
URL http://dx.doi.org/10.1016/j.jss.2018.07.001

This talk summarizes my research expertises in sustainable computing, and the contributions made in two key domains in relation with the workshop: software engineering and green IT.

In terms of software engineering, I have some contributions in the model-driven engineering and self-adaptive systems communities. Some of my recent work especially deals with domain-specific language design and formal methods for specifying the reconfiguration space and the legal states a software system can be in. With my co-authors we have then applied some solutions coming from the control theory domain to generate some discrete event controllers that ensure that the system under control stays within the boundaries that have been specified. This work have been applied to the znn.com exemplar well-known in the self-adaptive system community.

In terms of green IT, me and my group of colleagues have developed in the recent years the PowerAPI (http://www.powerapi.org) library that enables to implement software-defined power meters to measure the energy induced by software systems. Among the goals that are pursued, we want to be able to identify energy hotspots in software systems, be able to rank web sites and services according to their energy footprint, and infer the energy model of hardware components. On this last point, we especially showed that the heterogeneity of modern CPU is so vast that one cannot a priori define a realistic power model (due to some very high variability, and a very high number of available hardware performance counters to potentially monitor). To solve this problem, we devised a solution where we applied some machine learning techniques to learn the power models.

3.26 Modeling for Sustainability: Lessons from Air Quality Decision-Making

Noelle Selin (MIT – Cambridge, US)

Sustainability is a critical challenge for engineering research and education as a (and perhaps the) critical societal challenge of the 21st century. For sustainability science, key core questions involve modeling: specifically, how theory and models can be formulated to better account for human-environment interactions, and how society can most effectively guide human-environment systems towards a sustainability transition [1]. Previous research suggests lessons for researchers (and modelers) interested in crafting usable knowledge for sustainable development [2]. Synthesis of previous scientific assessment efforts has shown that for research to be effective in influencing policy, it needs to be perceived by stakeholders to be credible, salient, and legitimate [3].

In the domain of air quality, useful lessons can be gleaned through efforts to understand the pathways from policies that control human activities and emissions, through the fate and transport of atmospheric pollutants, to exposure and health impacts. Simulating these pathways involves linking different sorts of models (economic, atmospheric, and health impact modeling) as well as accounting for system interactions and decision-making through case studies and policy experiments. In this talk, I address how the goal of having impact on sustainability-relevant societal challenges such as air quality can influence model-based research, through three mechanisms: scientific assessment processes, co-production with stakeholders, and co-production with boundary organizations. Examples of these different mechanisms in practice are described through examples of modeling mercury pollution [4], evaluating the impact of climate action on air quality outcomes [5], and assessing the co-benefits of U.S. climate policy [6]. I then examine how a policy-driven orientation can affect decisions about model scale (setting boundaries and resolution [7], complexity (simplifying processes [8], and uncertainty evaluation (evaluating end-member analyses [9] and conducting model ensembles). Experiments in model-based decision-making are summarized, showing that when users engage themselves with models, individuals are more likely to find win-win sustainability trade-offs [10], and groups find consensus faster [11]. Sustainability effects of policies can also be evaluated quantitatively using frameworks from inclusive wealth accounting, as shown by a case study of non-fossil energy investment in Saudi Arabia [12]. Simple model equations can potentially be more effective than complex models in informing policy, such as new metrics to inform global mercury negotiations [13]. Further case studies are needed to help inform the development of new models and frameworks to address sustainability as a systems problem.

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3.27 Requirements Engineering for Evolution Towards Sustainability

Norbert Seyff (FH Nordwestschweiz, CH)

Continuous requirements elicitation is an essential aspect of software product evolution to keep systems aligned with changing user needs. However, current requirements engineering approaches do not explicitly address sustainability in the evolution of systems. Reasons include a lack of awareness and a lack of shared understanding of the concept of sustainability in the RE community. Identifying and analysing the effects of requirements regarding sustainability is challenging, as these effects can have an impact on multiple stakeholders and manifest themselves in one or more sustainability dimensions at different points in time. We argue that tailored requirements engineering approaches are needed which allow the engagement of a large number of stakeholders (including users and domain experts) in a continuous cycle of negotiation regarding the potential effects of requirements on sustainability.

3.28 Software Architecture Modeling for Sustainability: WTFs/Minute

Colin Venters (University of Leeds, GB), Christoph Becker (University of Toronto, CA), Stefanie Betz (KIT – Karlsruher Institut für Technologie, DE), and Birgit Penzenstadler (California State University, US)

Joint work of Colin C. Venters, Rafael Capilla, Stefanie Betz, Birgit Penzenstadler, Tom Crick, Steve Crouch, Elisa Yumi Nakagawa, Christoph Becker, Carlos Carrillo
Main reference Colin C. Venters, Rafael Capilla, Stefanie Betz, Birgit Penzenstadler, Tom Crick, Steve Crouch, Elisa Yumi Nakagawa, Christoph Becker, Carlos Carrillo: "Software sustainability: Research and practice from a software architecture viewpoint", Journal of Systems and Software, Vol. 138, pp. 174–188, 2018.
URL http://dx.doi.org/10.1016/j.jss.2017.12.026

This talk highlights the role that software architectures play in the development of technically sustainable software. It is argued that software architectures are the primary carrier of system qualities (NFR) i.e. pre-system understanding, and influence how developers are able to understand, analyze, extend, test and maintain a software system i.e. post-deployment system understanding. As such, software architectures provide a mechanism for reasoning about quality attributes. This presentation proposes that sustainable software architectures are fundamental to the development of technically sustainable software to address architectural drift and erosion, decay, and architectural knowledge vaporization [1].

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3.29 Human Values in Software Engineering – Where Are They?

Jon Whittle (Monash University – Clayton, AU)

After decades of research and practice in software engineering, a range of well-established methodologies have been developed that (generally speaking) help to produce software that has the right functionality, at an affordable cost, is safe, secure, and safeguards data privacy. However, there are a whole range of 'human values' that have not been considered in software engineering, such as gender diversity, transparency, integrity, social responsibility, family or corporate values. No software is values-free, however. And so this talk argues that software designers ought to explicitly consider human values in software design. We see this as a new paradigm in software engineering which has a number of challenges including how to specify human values, how to trace human values throughout the software lifecycle, and how to measure values in software.

3.30 Modelling for Sustainability – 5 minute introduction

Paul Young (Lancaster University, GB)

This presentation addresses the initial questions set for the workshop (what is modelling? what is modelling for sustainability?) from the point of view of an atmospheric/climate scientist. Our definition of modelling mirrors that used by several other fields represented here, but our ideas of "sustainability" are more coupled to global sustainability/sustainable development issues as defined by the 1987 Bruntland Report (https://en.wikipedia.org/wiki/Brundtland_Commission). Other relevant issues of sustainability relate to the sustainability of the code: well documented and re-usable, but also efficient from the point of view of energy consumption.

4 Working Groups

4.1 Modeling for Sustainability: A Multidisciplinary Problem

Betty H. C. Cheng (Michigan State University – East Lansing, US)

In addition to providing definitions for model and modeling for sustainability, this talk briefly overviews previous experiences of modeling for sustainability. Lessons learned and challenges from a sustainability project from 20 years earlier are interestingly still applicable in current day efforts with sustainability. The main difference is the scale and complexity of the models, data, and integration have increased dramatically, largely due to the technological advances in the past two decades. Three key challenges are highlighted: data access and integration; model integration; and role and impact of uncertainty.

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